Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Chemistry 4 (2012) 224 – 231

Procedia Chemistry

Green Synthesis of Some Calix[4]resorcinarene under Microwave Irradiation

R.E. Sardjono[a,*], A. Kadarohman[a], A. Mardhiyah[a]

[a] *Department of Chemistry Education of Indonesia University of Education, Dr. Setiabudhi avenue 229, Bandung 40154, Indonesia*

Abstract

A green synthetic procedure for the preparation of some calix[4]resorcinarenes using a household microwave oven has been carried out. This method represents a very rapid heating alternative to the conventional method that involves very long time of reactions (from 20-24 h in conventional heating to 5-8 min in microwave irradiation). C-4-hydroxy-3-methoxycalix[4]resorcinarene (CHMPCR), C-4-methoxyphenylcalix[4]resorcinarene (CMPCR) and C-2-phenylethenilcalix[4]resorcinarene (CPECR) was achieved by placed of resorcinol, an aldehyde, HCl and ethanol inside a household microwave oven. The product was recrystallized by methanol and analyzed by spectral analysis (FTIR, H-NMR and MS). Optimization of reaction was carried out in variation of microwave power, reaction times and reactant composition. The result shows that optimum condition of synthesis of C-4-hydroxy-3-methoxycalix[4]resorcinarene (CHMPCR) with microwave irradiation were at microwave power 332 W, reaction time 8 min and the mole ratio of resorcinol and 4-hydroxy-3-methoxyphenylbenzaldehyde 1:1. This parameter gave product in 97.8 % (53.7% after recrystallization). The CPECR synthesis using resorcinol and cynnamaldehyde (1:1) at microwave power 332 W for 5 min afforded the product in 97.3% (44.5% after recrystallization). Whereas the reaction of resorcinol and 4-methoxyphenylbenzaldehyde (1:1.2) at microwave power 264 W for 5 min gave CMPCR in 99.5% (68.6% after recrystallization).

Keywords: Calix[4]resorcinarene; vanillin; cinnamaldehyde; anisaldehyde; microwave.

1. Introduction

Calix[4]resorcinarene macrocycles are one of the calixarene macrocycles which were synthesized from resorcinol and an aldehyde. These macrocycles are the subject for increasing interest in the field of supramolecular chemistry or host-guest chemistry as basic skeleton for the synthesis of host compounds

* Corresponding author. Tel.:+62-22-2000579; fax:+62-22-2000579
E-mail address: ratnaeko@upi.edu

1876-6196
doi:10.1016/j.proche.2012.06.031

for cations, anions or neutral molecules. Calixarene have been used in many fields, such as liquid crystals[1], extractions [2], sensors [3], membranes [4], receptors [5], surfactants and catalyst [6], or stationary phase of chromatography [7,8].

Synthesis of calix[4]resorcinarene was generally carried out by reflux using ethanol as a solvent in abundance. This reaction gives product in good yield. Unfortunately, it takes long reaction time (20-24 h), so this method is not considered as environmentally friendly reaction.

The first microwave assisted synthesis of calix[4]resorcinarene has been done using 12-tungstophosphoric acid Keggin-type ($H_3PW_{12}O_{40}.13H_2O$) and concentrated HCl as a catalyst. Excellent isolated yields (up to 90%) were attained within short reaction times (typically, 3-5 min) when the reaction was performed under microwave irradiation [9].

This article describes the optimization synthesis of calix[4]resorcinarenes from vanillin (4-hydroxy-3-methoxyphenylbenzaldehyde), cinnamaldehyde and anisaldehyde (4-methoxyphenylbenzaldehyde) under microwave irradiation. Vanillin can be founded in vanili plants (*Vanilla planifolia*), cinnamaldehyde comes from cinnamon oil and anisaldehyde can be obtained from anise oil. Vanili plant (*Vanilla planifolia*), cinnamon oil and anise oil are Indonesia's natural resources which can be developed as raw material for synthesis certain calix[4]resorcinarenes that leads to an increasing of their utility and economic values.

Synthesis calix[4]resorcinarenes from vanillin, cinnamaldehyde and anisaldehyde have been done at previous research under conventional heating. The reaction temperature of synthesis calix[4] resorcinarenes were between 73-78 °C while reaction time were between 15-30 h [10]. Good yield of desired product is received. However, high temperature and long reaction time that lead to high energy and solvent consumption where in turn leading to excessive waste production that are environmentally unfriendly and expensive to deal with. Hence in this research, we conducted synthesis of each described calix[4]resorcinarene under microwave irradiation that expected to be more efficient, simple and green reaction.

2. Experiment

2.1. Chemicals

Resorcinol, vanillin, cinnamaldehyde, anisaldehyde, ethanol, concentrated HCl, aquadest, methanol, acetonitrile, acetone and DMSO were purchase from Sigma Chemicals Co.

2.2. Instruments

Microwave *Electrolux*, Fourier Transform Infra Red (FTIR) *Shimadzu 8400*, Mass Spectroscopy (MS) *Waters LCT Premier X6* and Proton-Nuclear Magnetic Resonance (^{1}H-NMR) *JEOL ECA 500 MHz*.

2.3. Synthesis of C-4-hydroxy-3-methoxphenilcalix[4]resorcinarene (CHMPCR)

Concentrated HCl (0.5 mL) was added to beaker glass which contained resorcinol solution (0.55 g, 5 mmol) and vanillin (0.76 g, 5 mmol) within 50 mL of ethanol. The mixture was stirred with magnetic stirrer at room temperature for 5 min. The mixture was placed in the microwave oven with microwave power 264 W during 5 min. The solid phase that formed from microwave reaction was washed with aquadest and then was recrystallized with methanol. The desired product was obtained in 53.7%; FTIR: 3423.4 cm^{-1} (OH), 2939.3 cm^{-1} (stretching CH sp^3), 1379.0 cm^{-1} (bending CH sp^3), 1612.4 cm^{-1} and 1517.9 cm^{-1} (C=C benzene), 1190.0 cm^{-1} (C-O); MS: $[M]^+$ (calc: *m/z* 976.29; found 976.29); δ_H (500

MHz, DMSO and H_2O) isomer C_{4v}: 5.55 (s,2H,CH), 8.05 (s,2H,OH), 8.44 (s,4H,OH). Isomer C_{2v}: 5.40 (s,1H,CH), 7.85 (s,1H,OH), 8.34 (s,2H,OH). Isomer C_{4v} and C_{2v}: 4.39 (s,4H,OCH_3), 6.08-6.43 (m,5H,benzene). Ratio of C_{4v} and C_{2v} was 2:1.

2.4. C-2-phenylethenilcalix[4]resorcinarene (CPECR)

Into a beaker glass which contained resorcinol (0.55 g , 5 mmol) and cinnamaldehyde (0.66 g, 5 mmol) within 50 mL of ethanol, 0.5 mL of concentrated HCl was added. The mixture was stirred at room temperature until homogeneus. The mixture was placed inside the microwave with microwave energy 264 W during 5 min. The solid phase that formed from microwave reaction was washed with aquadest and then it was recrystallized with methanol. The desired product was obtained in 97.3% before recrystallisation; FTIR : 3382.9 cm^{-1} (OH), 2927.7 cm^{-1} (*stretching* CH sp3), 1384.8 cm^{-1} (*bending* CH sp3), 3026.1 cm^{-1} (*stretching* CH sp2), 1620.1 cm^{-1} and 1494.7 cm^{-1} (C=C benzene), 1109,0 cm^{-1} (C-O); MS: $[M]^+$ (calc: m/z 896.33, found 896.32); δ_H (500 MHz, methanol) isomer C_{4v} : 9.64 (s , 1H , OH). Isomer C_{2v} : 9.63 (s , 1H , OH). Isomer C_{4v} and C_{2v} : 6.30-6.32 (s , 1H , CH sp3) , 6.73-6.78 (m , 2H , CH sp2) , 7.42-7.66 (m , 7H , benzene). Comparation of C_{4v} and C_{2v} was 1:1.

2.5. C-4-methoxyphenylcalix[4]resorcinarene (CMPCR)

Resorcinol (0.55 g, 5 mmol), anisaldehyde (0.68 g, 5 mmol), ethanol (50 mL) and concentrated HCl (5 mL) was mixed to a beaker glass. The mixture was stirred at room temperature for 5 min. The homogeneous mixture was placed into the microwave oven during 5 min with microwave power 264 W. The solid phase that formed from microwave reaction was washed with aquadest and then it was recrystallized with methanol. The CMPCR was obtained in 68.67%.; FTIR : 3394.5 cm^{-1} (OH), 2937.4 cm^{-1} (*stretching* CH sp3), 1380.9 cm^{-1} (*bending* CH sp3), 3001.0 cm^{-1} (*stretching* CH sp2), 1608.5 cm^{-1} and 1510.2 cm^{-1} (C=C benzene), 1182.3 cm^{-1} (C-O); MS : $[M]^+$ (calc: m/z 912.31, found 912.3136); δ_H (500 MHz, acetone-water 1:1) isomer C_{4v} : 3.69, 3.70, 3.71 (s , OCH_3), 6.61 (m , 1.6H , CH sp2) , 6,64 (m , 0.4H , CH sp2) , 6.68 (m , CH sp2) , 6.75 (m , CH sp2) , 6.76 (m , 2.9H , CH sp2) , 6.77 (m , CH sp2). Isomer C_{2v} : 3.75 dan 3.77 (s , OCH_3), 6.62 (m , 0.3H , CH sp2) , 6.67 (m , 0.5H , CH sp2) , 6.74 dan 6.78 (m , CH sp2). Isomer C_{4v} and C_{2v} : 5.71 (s , 1H , CH sp3) , 6.36, 6.37, 6.38, 6.53, 6.59 (s , CH sp2) , 6.26 (s , 1.8H , OH).

2.6. Optimizing condition of synthesis

Optimizing synthesis of CHMPCR, CPECR and CMPCR were done at variation of microwave energy (182, 264, 332 and 400 W), reaction time (4, 5, 6, 7, 8 and 9 min) and the ratio of mole between resorcinol and aldehyde (vanillin, cinnamaldehyde and anisaldehyde) with ratio 1:1, 1:1.1 and 1:1.2.

3. Results and Discussion

3.1. Synthesis of CHMPCR

CHMPCR have been successfully synthesized from resorcinol and vanillin (4-hydroxy-3-methoxy benzaldehyde) in acidic condition, Figure1 using microwave oven for 5 min at microwave power 264 W. The result of the condensation reaction was red-violet solid phase which became peach colored solid after recrystallisation process.

Product was insoluble in water, ethanol, acetone and acetonitrile, but soluble in DMSO and the mixture of acetone and water with ratio 1:1. A successfully synthesis were showed by several spectral analysis has been described. Reaction was investigated in different microwave power, where reaction time and mole ratio between resorcinol and vanillin were remained. The results were showed in Table 1. Better yield were attained by increasing power of microwave irradiation up to 332 W and then decreased. This is due to the fact that molecules reactant absorbs more energy when irradiation power was increased. Nonetheless the excess of energy absorbed make particles movement randomized that causes decrease of yield obtained. That is also happened when reaction was performed in longer than its optimal reaction time, which shown in Table 2. Whereas Table 3 shows no significant impact that comes from change of mole ratio of reactants. Optimal reaction was performed at ratio of mole reactants 1:1, irradiated at 332 W for 8 min, giving product in 97.8% or 53.7% after recrystallization.

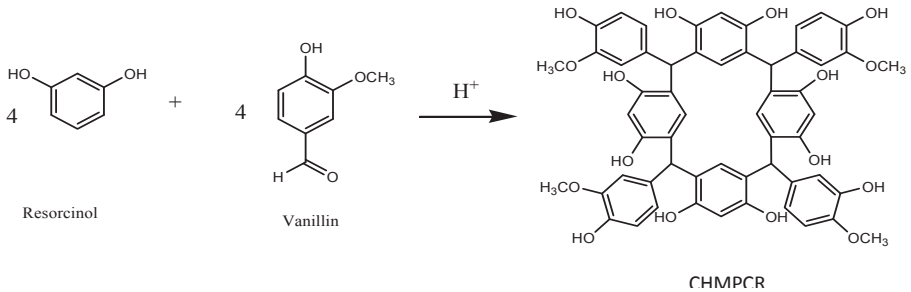

Fig 1. Reaction scheme of synthesis CHMPCR

3.2. Synthesis of CPECR

The process of reaction between resorcinol and cinnamaldehyde (3-phenyl-2-propenal) within acidic condition using microwave oven at microwave energy 264 W and reaction time was conducted for 5 min, produces CPECR, Figure 2. CPECR which has been attained was red-brown solid phase after recrystallization process. Structure of CPECR was confirmed by spectral analysis has been described in previous section.

Table 1. Change of Power of Microwave Irradiation*

Entry	Mole Ratio	Power (W)	Time (min)	Yield (%)
1	1 : 1	182	5	0
2	1 : 1	264	5	83.1
3	1 : 1	332	5	96.4
4	1 : 1	400	5	95.5

Table 2. Change of Power of Microwave Irradiation*

Entry	Mole Ratio	Power (W)	Time (min)	Yield (%)
1	1 : 1	332	4	94.5
2	1 : 1	332	5	96.4
3	1 : 1	332	6	97.3
4	1 : 1	332	7	95.7
5	1 : 1	332	8	97.8
6	1 : 1	332	9	66.9

Table 3. Change of Mole Ratio of Resorcinol and Vanillin*

Entry	Mole Ratio	Power (W)	Time (min)	Yield (%)
1	1 : 1	332	8	97.8
2	1 : 1.1	332	8	96.3
3	1 : 1.2	332	8	97.6

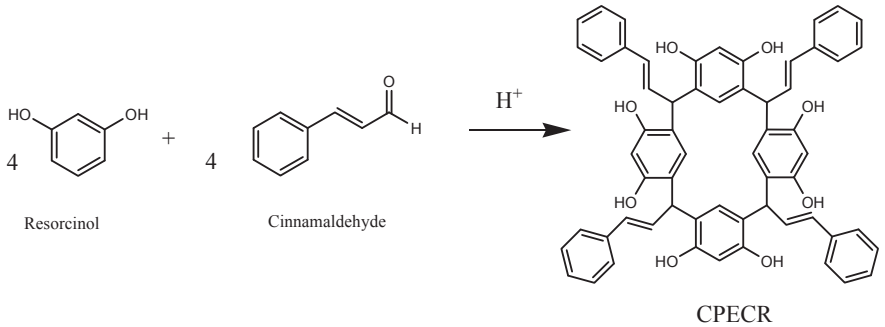

Fig. 2. Reaction scheme of synthesis CPECR

CPECR has good solubilty in some solvents, such as ethanol, methanol and acetone. Similar to the reaction of synthesis CHMPCR, effect of each different factor was investigated to obtain an optimal condition of reaction. Effect of microwave power, reaction time and mole ratio reactants were shown in Table 4, 5 and 6 respectively. Optimal reaction of CPECR was performed at ratio of mole reactants 1:1, irradiated at 332 W for 5 min, giving product in 97.9% before recrystallization.

Table 4. Change of Power of Microwave Irradiation*

Entry	Mole Ratio	Power (W)	Time (min)	Yield (%)
1	1 : 1	182	5	88.0
2	1 : 1	264	5	91.2
3	1 : 1	332	5	97.9
4	1 : 1	400	5	97.1

Table 5. Change of Power of Microwave Irradiation*

Entry	Mole Ratio	Power (W)	Time (min)	Yield (%)
1	1 : 1	332	4	91.3
2	1 : 1	332	5	97.9
3	1 : 1	332	6	96.8
4	1 : 1	332	7	91.7
5	1 : 1	332	8	81.1

Table 6. Change of Mole Ratio of Resorcinol and Cynnamaldehyde*

Entry	Mole Ratio	Power (W)	Time (min)	Yield (%)
1	1 : 1	332	5	97.9
2	1 : 1.1	332	5	93.2
3	1 : 1.2	332	5	88.1

3.3. Synthesis of CMPCR

We also report synthesis of CMPCR from resorcinol and anisaldehyde (4-methoxybenzaldehyde) within acidic condition, Figure 3 using microwave oven at microwave energy 264 W for 5 min. The product of CMPCR which has been attained was peach solid phase for CMPCR after recrystallization process. CMPCR was insoluble in water, methanol and organic solvent like acetone, but soluble in mixture of acetone and water with ratio 1:1.

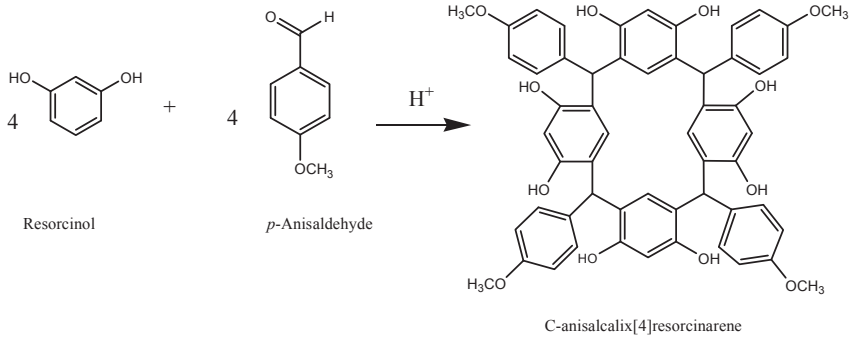

Fig 3. Reaction scheme of synthesis CMPCR

The optimum conditions of synthesis CMPCR using microwave were attained at a microwave energy of 264 W, reaction time during 5 min and the ratio of mole resorcinol and anisaldehyde was 1:1.2.

Table 7. Change of Power of Microwave Irradiation*

Entry	Mole Ratio	Power (W)	Time (min)	Yield (%)
1	1 : 1	182	5	0
2	1 : 1	264	5	85.3
3	1 : 1	332	5	69.7
4	1 : 1	400	5	67.6

Table 8. Change of Power of Microwave Irradiation*

Entry	Mole Ratio	Power (W)	Time (min)	Yield (%)
1	1 : 1	264	4	0
2	1 : 1	264	5	85.3
3	1 : 1	264	6	60.6
4	1 : 1	264	7	74.5
5	1 : 1	264	8	68.5

Table 9. Change of Mole Ratio of Resorcinol and Anisaldehyde*

Entry	Mole Ratio	Power (W)	Time (min)	Yield (%)
1	1 : 1	264	5	85.3
2	1 : 1.1	264	5	70.9
3	1 : 1.2	264	5	99.5

*The yields of CHMPCR, CSK4R and CMPCR above were the products yields before purification (recrystallisation).

3.4. Effect of Microwave Dielectric Heating in Synthesis Calix[4]resorcinarenes

A classical synthesis of calix[4]resorcinarenes was generally performed in long reaction times which automatically leads to high energy consumption. In addition, high amount of solvent or catalyst needed gives rise to large degree waste production which is environmentally and economically unfriendly. In contrast to that, microwave dielectric heating gives some merits such as shorter reaction time, simpler procedure, better yield and being beneficial in environment protection [11].

Microwave was the alternative method to input the energy onto the chemical reaction. Microwave heating uses the ability of some compounds (liquids or solids) to transform electromagnetic energy into heat [12]. Energy transmission is produced by dielectric losses, which is in contrast to conduction and convection processes observed in conventional heating [12]. The magnitude of heating depends on the dielectric properties of the molecules [12].These characteristics mean that absorption of the radiation and heating may be performed selectively [12]. Microwave irradiation is rapid and volumetric, with the whole material heated simultaneously [12]. Without contacting with the vessel wall, the energy can be directly absorbed by molecules reactants so that reduce the reaction time. Except that, within reaction process using microwave irradiation, the solvent would reach its boiling point within short time so that superheating will be occurred. Superheating was boiling point reached which is higher than its real boiling point, so that the reactions will occured faster [12].

Mechanism process that occured within synthesis reaction of calix[4]resorcinarenes using microwave irradiation was dipolar polarization mechanism. The principle of this mechanism is occured because of dipoles interaction between polar molecules when irradiated with microwave. A dipole is sensitive to external electric fields and will attempt to align itself with the field by rotation. The applied field provides the energy for this rotation [13]. The energy from that process is heat energy, so that its known with thermal effect (dielectric heating) [14].

In this review, we report the use of minimum amount of solvent. Ethanol was selected as a solvent not only its ability to dissolve all reactants used, but also its ability to perform superheating effect when it was radiated with microwave which gives contribute to reduction of reaction time from hours using conventional heating to minutes using microwave dielectric heating.

4. Conclusion

From the research that have been done, we conclude that the synthesis of cyclic tetramers calix[4]resorcinarenes from vanillin, cynnamaldehyde and anisaldehyde could be performed under microwave irradiation within very short reaction time if compared to the conventional heating. The optimum conditions of synthesis CHMPCR using microwave irradiation were at microwave energy 332 W, reaction time 8 min and mol ratio between resorcinol and vanillin was 1:1 giving yield in 53.7%. The optimum conditions of synthesis CPECR with microwave irradiation were at microwave energy 332 W, reaction time 5 min and mol ratio between resorcinol and cynnamaldehyde was 1:1, giving yield in 44.5%. The optimum conditions of synthesis CMPCR with microwave irradiation were at microwave energy 264 W, reaction during 5 min and mol ratio between resorcinol and anisaldehyde was 1:1.2, giving yield in 44.3%.

References

[1] Patel R.V., Panchal J.G., Rana V.A. and Menon S.K., *J. Inc. Phenom. Macrocycl. Chem*. 2009; **67**(1-2): 73-79.

[2] Mocerino M., Mishima K., Nishioka H., Yaneda A., Ouchi M., *Anal. Sci*. 2001; **17**: i1223-i1224.

[3] Britz-Mckibbin P., Chen D.D.Y., *Anal. Chem*. 1998;**70**: 907-912.

[4] Jain V.K., Pillai S.G., Pandya R.A., Agrawal Y.K., Shrivastav, P.S., *Anal. Sci*. 2005; **21**: 129-135.
[5] Moon B.S., Kim S.K., Kang B.G., Lee J.H., Toon J., Lee K.D., *Bull. Korean.Chem. Soc*. 2003; **24**(1): 133-136.
[6] Shinkai S., Mori S., Arimura T., Manabe O., *J. Am. Chem. Soc*. 1986; **108**: 2409-2416.
[7] Hamilton., K., *Dissertation*, Department of Chemistry, Lousiana State University, Lousiana; 2003.
[8] Suh, J.K., Kim, I.W., Chang, S.H., Kim, B.E., Ryu, J.W., Park, J.H., *Bull. Korean Chem. Soc*. 2001; **22**(4): 409-412.
[9] Hedidi, M., Hamdi, S.M., Mazari, T., Boutemer, B., Rabia, C., Chemat, F., Hamdi, M., *Tetrahedron* 2006; **62**(24): 5652-5655.
[10] Sardjono, R.E., *Dissertation*, Department of Chemistry, Gadjah Mada University, Yogyakarta, 2007.
[11] Baozhi L., Gengliang Y., Jinsong Z., Kefang D., *E-J. Chem.* 2005; **2**(6): 70-74.
[12] de La Hoz, A., Di ‘az-Ortiz, A., Moreno, A., *Chem. Soc. Rev*. 2005; **34**: 164-178.
[13] Lidstrom P., Tierney J., Wathey B., Westman J., *Tetrahedron* 2001; **57**: 9225-9283.
[14] Perreux L., Loupy A., *Tetrahedron* 2001; **57**: 9199-9223.